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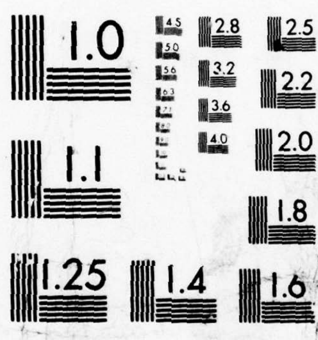

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PROPOSED GUIDELINES FOR SITE INVESTIGATIONS FOR FOUNDATIONS OF NUCLEAR POWER PLANTS

by

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Site investigations for nuclear power plants are necessary to determine the geotechnical conditions that affect the design, cost, performance, and safety of the plants. Major considerations for analysis and design include the bearing capacity of foundation materials, the total and differential settlements of structures under static and earthquake loading conditions, the stability of cuts and slopes in soil and rock under static and earthquake loading conditions, the propagation of earthquake-induced motions through —— (Continued)

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20. Abstract (Continued).

Cont. underlying deposits, and the potential for liquefaction of soils. The stability of foundations during construction must also be assured.

The purpose of the proposed guidelines is to describe programs of geological and engineering site investigations that would be adequate to evaluate the safety of the site and to provide the parameters needed for engineering analysis and design of foundations and earthworks. General requirements for site investigations are discussed. Methods of subsurface investigation, including their applicability, limitations, and pitfalls, are described. Proposed rules for spacing and depth of subsurface exploration for various kinds of seismic Category I structures are given.

PREFACE

This report was prepared by the U. S. Army Engineer Waterways Experiment Station (WES) for the U. S. Nuclear Regulatory Commission (NRC) under Contract number AT(49-24)-0104, for use by the NRC in developing Regulatory Guide 1.132, "Site Investigations for Foundations of Nuclear Power Plants." Regulatory Guide 1.132 as issued by the NRC differs in some particulars from the guidelines proposed in this report.

The report was prepared during the period of August 1974 to June 1975 by Dr. A. G. Franklin of the Earthquake Engineering and Geophysics Division (EE&GD), Geotechnical Laboratory (GL), WES. The work was done under the general supervision of Mr. Walter C. Sherman and Dr. Francis G. McLean, Former Chiefs, EE&GD, and Mr. James P. Sale, Chief, GL.

The Director of the WES during the preparation of the report was COL G. H. Hilt, CE. Technical Director was Mr. F. R. Brown.

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CONVERSION FACTORS, U. S. CUSTOMARY TO METRIC (SI) UNITS OF MEASUREMENT

U. S. customary units of measurement used in this report can be converted to metric (SI) units as follows:

Multiply	By	To Obtain
feet	0.3048	metres
feet per second	0.3048	metres per second
inches	25.4	millimetres
inches per second	25.4	millimetres per second
kips (force) per square foot	47.88026	kilopascals
miles (U. S. statute)	1.609344	kilometres
pounds (force) per square foot	47.88026	pascals
pounds (force) per square inch	6894.757	pascals
pounds (mass)	0.4535924	kilograms
pounds (mass) per cubic foot	16.01846	kilograms per cubic metre

PROPOSED GUIDELINES FOR SITE INVESTIGATIONS FOR FOUNDATIONS OF NUCLEAR POWER PLANTS

A. INTRODUCTION

Appendix A to 10 CFR Part 100 establishes requirements for site investigations for nuclear power plants to permit an evaluation of the site and to provide information needed for seismic evaluation and engineering design. Included in the required investigations is the development of information relevant to stratigraphy, lithology, geologic history, and structural geology of the site, and to the static and dynamic engineering properties of the materials underlying the site.

Safety-related site characteristics are identified in detail in Section 2.5 of Regulatory Guide 1.70, "Standard Format and Content of Safety Analysis Reports for Nuclear Power Plants." Proposed Regulatory Guide 4.7, "General Site Suitability Criteria for Nuclear Power Stations," discusses major site characteristics, including those related to geology and seismology, that would be considered in determining the suitability of a particular site.

The needs of special attention to seismic considerations and to concern for public safety require that site explorations be carried out with a sufficient degree of comprehensiveness and detail to assure a high level of confidence in the results. This guide discusses programs of geological and engineering site investigations that are needed (a) to evaluate the safety of the site from the standpoint of the performance of foundations and earthworks under all conditions that might reasonably be anticipated,

including the occurrence of earthquakes; and (b) to provide the parameters needed for engineering design of foundations and earthworks. It is the purpose of this guide to describe programs of site investigation that would be considered adequate to meet those needs. This guide does not deal with hydrologic investigations, except in the context of foundation engineering. It does not discuss methods of surface geophysical exploration, or of laboratory testing, which will be considered in future Regulatory Guides.

B. DISCUSSION

Site investigations for nuclear power plants are necessary to determine the geotechnical conditions that affect the design, cost, performance, and safety of the plants. The investigations must, first, produce the information needed to define the overall site geology, which is needed for an understanding of the relationships among the strata and geological materials of the site, and for an appreciation of the implications of observed site conditions with respect to potential geologic hazards.

Major considerations for analyses and design include the bearing capacity of foundation materials, the total and differential settlements of structures under static and earthquake loading conditions, earth pressures against walls under static and earthquake loading conditions, the stability of cuts and slopes in soil and rock under static and earthquake loading conditions, the propagation of earthquake-induced motions through underlying deposits, and the potential for liquefaction of soils under shaking that might be imposed by earthquakes. The stability of foundations during construction must also be assured.

To assure the functional integrity of foundations of safety-related structures, site investigations must meet the following geological and geotechnical needs:

i. To determine in detail the geologic origin, types, thicknesses, sequence, and extent of soil and rock strata on the site;

ii. To determine groundwater conditions;

iii. To determine the static and dynamic engineering properties of foundation materials supporting safety-related structures, by means of in situ tests and laboratory testing of suitable samples;

iv. To detect and define any adverse geological conditions, such as cavities, faults, fissures, or bodies of compressible or unstable soil, which could endanger any safety-related structures.

Although a site may share many common features with others, each one is unique, and it is not possible for any plan or guide for site investigations to cover all circumstances and contingencies. The general needs listed above should take precedence over other rules, and be used as a guide in circumstances not otherwise provided for.

The investigative effort required for a nuclear power plant should naturally be greatest in intensity at the locations of the Category I structures, and should vary in intensity and kind in other areas according to their spatial and geological relations to the site. For the purposes of this Guide, Exploratory Zones are designated as follows:

i. Zone I comprises the immediate areas of foundations for safety-related (Seismic Category I) structures or systems, in addition to any other areas in which foundation failures or ground instability could endanger safety-related structures.

ii. Zone II comprises those areas within the site boundary, or in which structures or systems appurtenant to the power plant are located, but not included in Zone I.

iii. Zone III comprises those areas, not included in Zones I and II, in the environs of the site and having close geological affinities to the site area, and in which an understanding of the geological conditions is needed for a complete assessment of the geology of the site.

C. REGULATORY POSITION

1. General Requirements

Site investigations for nuclear power plants are required to determine the geological and geotechnical conditions that affect design, cost, performance, and safety. They should be adequate, in terms of thoroughness, suitability of the methods used, and quality of execution of the work, to assure the functional integrity of the foundations of safety-related structures. They should provide the information needed to assess the geology of the site and to perform engineering analysis and design with a high degree of confidence that foundation conditions are not less favorable than those considered.

Information to be developed for Safety Analysis Reports is identified in detail in Section 2.5 of Regulatory Guide 1.70. Types of documentation that are described include topographic and geologic maps; plot plans, showing locations of major structures, borings, trenches, and excavations; geologic profiles; and profiles showing locations and subgrade elevations of Category I structures in relation to subsurface materials. These data should be in sufficient detail and should be integrated to develop a unified view of the project and the geologic and geotechnical conditions affecting it.

In addition, procedures and equipment used to carry out the field operations should be thoroughly documented. Such documentation will facilitate the process of review of Safety Analysis Reports, and can help in demonstrating the accuracy and reliability of the results and the thoroughness of the investigation.

2. Reviews and Surface Investigations

Effective planning of subsurface investigations and intelligent interpretation of the data obtained requires an understanding of the general geology of the site, and the subsurface investigations should be accompanied or preceded by a thorough geologic assessment of the site by means of surface investigations and review of available documentary materials. The assessment of the site geology requires study of the broader regional geology as well as the geology of the immediate site area. In most cases, study of geology over areas larger than the immediate area of the site can be done by review of available documentary materials and by reconnaissance methods, including study of aerial photographs and remote sensing imagery. Documentary materials (current and historical) that should be reviewed include:

i. Topographic maps

ii. Geologic maps

iii. Engineering geologic maps

iv. Soil survey maps

v. Geologic reports and other geological literature

vi. Geotechnical reports and other geotechnical literature

vii. Well records and water supply reports

viii. Oil well records

ix. Hydrological maps

x. Hydrological and tidal data and flood records

xi. Climate and rainfall records

xii. Mining history, old mine plans, and subsidence records

xiii. Seismic data and historical earthquake records

xiv. Newspaper records of landslides, floods, earthquakes, subsidence, and other events of geological or geotechnical significance.

xv. Records of performance of other structures in the vicinity.

In addition, local experience with regard to special or unusual problems, such as swelling shales, occurrences of gas, cavities in nonsoluble rocks, or areal subsidence caused by pumping of water or oil from wells, should be investigated by consultation with individuals, institutions, or firms having local experience. These reviews should be documented, in summary form, for inclusion in Safety Analysis Reports.

The site investigation should include detailed surface exploration of the site (Zones I and II) and its environs (Zone III); further detailed surface exploration may be required in areas outside Zone III if it is needed for an adequate understanding of the site geology or where it is required for detailed investigation of surface faulting in accordance with Section IV of Appendix A to 10 CFR Part 100. Surface exploration for the assessment of site geology may be carried out with the use of any appropriate combination of geological, geophysical, or engineering techniques, but normally should include the following:

i. Detailed mapping of topographic, hydrologic, and cultural features with scales and contour intervals suitable for engineering design. For

offshore sites, coastal sites, or sites located near lakes or rivers, mapping should include detailed hydrographic surveys and surveys of bottom topography to the extent that they are needed for site evaluation and engineering design. Positions of all boreholes, soundings, trenches, exploratory pits, and geophysical surveys should be surveyed, in both plan and elevation, and shown on maps. All surveys should be related to a fixed and stable datum, and should be made to standards of accuracy commensurate with needs for site evaluation and engineering design.

ii. Detailed geological analysis of aerial photographs, and other remote-sensing imagery as appropriate. This analysis should include mapping of observable rock outcrops, soil conditions, evidence of past landslides or soil liquefaction, faults, fracture traces, linears, and lineaments.

iii. Detailed mapping of surface geology.

iv. Detailed mapping of features related to groundwater, such as rivers, streams, surface drainage channels, lakes, ponds, springs, and sinks.

3. Groundwater Observations

Knowledge of the location of groundwater tables, the relation of groundwater to bodies of surface water, and variations associated with seasons or tides is required for foundation analyses of all kinds, including liquefaction and ground-response analyses. Groundwater observations made in borings at the time the borings are made can be grossly misleading, and should not be relied on for engineering applications. Groundwater observations should be made by means of properly installed piezometers, read at regular intervals from the time of installation through the construction period. Piezometer

installations should be made in at least one-fourth of the principal borings*, as described in Paragraph 6 of this Section, or groundwater observation wells with equivalent spacing. Where borings or other evidence indicates the presence of perched groundwater tables or artesian pressures, piezometer installations should be made to determine each piezometric level independently. Care should be taken in the design and installation of piezometers to prevent communication between aquifers. When artesian pressures are encountered in borings, the occurrence should be noted on boring logs and the artesian heads should be measured.

Methods of installation of piezometers are discussed by Hvorslev (11)** pp. 79-81, and in Appendix A of Reference 24.

4. Requirements Related to Site Conditions

General. For all sites, exploration must be carried out so that it meets the general needs stated in Section C.1. The present section deals with requirements for subsurface exploration as they are related to various geologic conditions that may be encountered on the site. Additional discussion of problem conditions may be found in Appendix A of Reference 26 and in Reference 8.

For all foundation materials, it is necessary to determine the shear strengths in all zones subjected to significant imposed stresses, or to establish that they are adequate to support the imposed loads with an appropriate factor of safety. Similarly, it is necessary to determine the compressibilities and swelling potentials of all materials in zones subjected to significant changes of compressive stresses, or to establish that the

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* Defined in Appendix B.

** Numbers in parentheses refer to the numbered entries in Appendix A.

deformations will be less than some safe value. These needs may be satisfied by suitable in situ tests* and classification tests in dense, competent materials, or may require, in addition, the recovery of undisturbed samples for appropriate laboratory testing. Determination of dynamic modulus and damping values is required for all soil strata for the purpose of earthquake response analyses; this may be done by recovery of suitable undisturbed samples for laboratory testing, and/or by appropriate in situ tests.

Sampling of soils should include, at a minimum, recovery of samples for indentification and classification of all soil strata, and for water content and density measurements in materials with cohesion, from all principal borings. Samples should be obtained at all depths where changes of material are encountered. The sampling frequency needed is dependent on the variability of the soils and on the nature of the structures involved; in most cases, samples should be obtained at intervals of no more than three feet. Where sampling is not continuous, samples should not be taken at the same depths in all borings, but should be arranged so that all soil intervals are represented by samples from some borings. In supplementary* borings, made for the purpose of defining some specific anomaly or soil body, sampling may be confined to the zone of specific interest.

In some kinds of problems, such as potential liquefaction or slope instability, relatively thin zones of weak or unstable soil contained within strata of more competent materials may be critical. Wherever there is evidence to suggest that such a condition should be considered, sampling in subsequent borings should be continuous through all suspect zones, or the sampling interval should be sufficiently small to assure that no critical

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* Defined in Appendix B.

zones will be overlooked. Additionally, at least one boring with such decreased sampling intervals should be made at the location of every Category I structure.

Where it is not possible to obtain continuous samples, or samples at sufficiently small intervals, in a single boring, equivalent samples may be obtained from a set of closely spaced borings. In such a set of borings, only one should be considered to be a principal boring.

Undisturbed samples of highest quality are obtained by carefully performed hand trimming of block samples in accessible excavations. However, it is normally not feasible to obtain samples at the requisite spacings and depths by this method alone because of the excessive effort and expense it would entail, and it is customary to use thin-wall tube samplers in borings for the major part of the undisturbed sampling in any site exploration program. The needed frequency of sampling is normally less in accessible excavations than in borings because the materials can be inspected in situ and sampling locations chosen in the most representative or critical materials. Where accessible excavations are used, they should be logged and mapped in detail, and representative samples should be taken of all materials encountered. Undisturbed samples should be taken so as to represent typical materials as well as materials that are critical or anomalous in terms of strength, compressibility, or density. They should be taken in sufficient number to provide average values of the material properties and to indicate their variability.

Rock. The engineering characteristics of rocks are dependent primarily on their structure, bedding, jointing, and weathering, and core samples are needed to observe these features. Rock intervals penetrated in principal borings should be sampled by suitable coring methods down to a depth at which bedding and jointing do not significantly affect the foundation

performance of the rock, and further where required for the investigation of zones that are critical to the evaluation of the site geology. Within the intervals significant to foundation performance, any zones of poor core recovery, dropping of rods, or lost circulation should be investigated by means of suitable logging or in situ observation methods to determine the nature, geometry, and spacing of any discontinuities. Where voids, channels, or fissures are encountered with soil filling, representative samples of the filling materials should be obtained.

Materials unsuitable for foundations. Materials such as vegetation, topsoil, peat, organic soil, muck, or soft clay are considered unsuitable for foundations of nuclear power plants. Whenever it has been determined that a body of soil is to be removed and wasted, because of undesirable properties or for other reasons, sampling and in situ testing should be done to the extent needed for identification and to establish the boundaries of the body with the degree of accuracy required by any analyses, such as earthquake response analyses, involving the adjacent materials.

Borrow materials. Post-construction performance of fills depends on the composition of the borrow materials and the methods of placement and compaction, and thus the requirements for exploration of borrow sources involve primarily the determination of the amount of borrow available, mapping its boundaries, and obtaining samples adequate for necessary laboratory testing, including determination of natural moisture contents. Sampling programs for borrow sources should provide representative samples with sufficient horizontal and vertical frequency to establish statistical measures of the material properties and their variability, and of sufficient size to permit laboratory tests for classification, gradation analyses,

compaction behavior, and, for granular materials, liquefaction behavior. The data obtained should be verified during the construction of the plant.

Where it has been determined that materials will be overexcavated and replaced as compacted backfill, they may be treated as borrow materials.

Moderately compressible or normally consolidated clays. Wherever materials of this type occur, consideration must be given to the problems of settlement, bearing capacity, slope stability, and ground response to seismic motions. The response of the foundation in these modes depends on the structure of the clay in situ, and thus reliable determination of material properties requires testing of undisturbed samples. Undisturbed samples should be obtained by means of suitable thin-wall tube samplers, or by methods which yield samples of equivalent quality. They should be continuous throughout the compressible strata in all principal borings.

Granular soils. Plants founded on granular soils require the consideration of bearing capacity, settlements under static and earthquake loading conditions, propagation of earthquake motions, and, if the soils are saturated or may become saturated during the operating life of the plant, possible liquefaction under earthquake loadings. The susceptibility of a soil to liquefaction depends on several factors, including its grain-size distribution, intergranular structure, degree of saturation, and density. In some cases, it is possible to establish the safety of a soil mass with respect to liquefaction by means of the grain-size distribution, as determined from representative samples, and conservative estimates of the density from the results of in situ tests, including the Standard Penetration Test, seismic velocity tests, and others, used in combination. The Standard Penetration Test, however, must be used with the utmost caution for this

purpose. Published correlations between the SPT blow count value and the relative density represent average trends of highly variable data, and may be unconservative. Generally, interpretation of relative density from SPT values requires a site-specific correlation made from a data base adequate to provide statistical validity for the correlation and the degree of uncertainty in it. In the absence of a correlation so obtained, the SPT may not be used as the sole criterion for evaluating the stability of granular deposits.

Where safety against liquefaction can not be clearly established by in situ tests, a program of undisturbed sampling will be required. Undisturbed samples should be obtained by means of fixed-piston, thin-wall tube samplers, with the use of drilling mud; or by methods which yield undisturbed samples of equivalent quality. Samples of all suspect strata should be obtained. Sufficient samples should be obtained to permit required laboratory testing for all relevant stress and earthquake loading conditions. The number of samples to be obtained and the number and spacing of required borings depend on the variability of the soil conditions, but they shou[illegible] epresent at least one boring at the location of each Category I structure. The sampling should be supplemented by splitspoon sampling and Standard Penetration Tests in principal borings in which undisturbed samples are not taken, or by cone penetration tests on equivalent spacing.

Boulders, gravel, or sand-gravel mixtures. Granular soils containing coarse particles are among the most difficult of materials for which to determine in situ properties, but some types may be potentially unstable under earthquake loading conditions, and the needs for determination of in situ properties are not less stringent than for soils that are easier to

sample and test. Minimal requirements are the determination of in situ density and the recovery of samples suitable for identification, mechanical analysis, and, when the need is indicated, laboratory testing of reconstituted samples for shear strength and liquefaction behavior.

In any material where the liquefaction potential is in question, the preferred method of investigation is by recovery of undisturbed samples. Because undisturbed samples of coarse granular soils can not be obtained in boreholes by presently available samplers, undisturbed sampling requires the use of trenches, pits, or other accessible excavations into the suspect zones. It may be possible in some cases to establish by means of evidence from suitable in situ tests that the density is within a range that, considering the grain-size distribution, obviates any reasonable possibility of ground instability under shaking imposed by the SSE. The SPT is not a suitable test for this purpose, since the presence of gravel-size particles makes the blow count values unreliable.

Subsurface cavities. Subsurface cavities may occur in water-soluble rocks, in lavas, and, less commonly, as the result of subterranean erosion in weakly indurated sedimentary rocks. Because of the solution susceptibility of limestones and their wide distribution, the occurrence of features such as cavities, sinkholes, and solution-widened joint openings is a common engineering problem. The present state-of-the-art of exploration and construction in areas of carbonate rocks is not wholly satisfactory, and many recent experiences have shown that solution features may be numerous even where satisfactory conditions are indicated by what appears by usual standards to be a large number of borings. For this reason, and because the degree of conservatism required for nuclear power plants is necessarily high,

any site on carbonate rocks should be considered suspect until its freedom from solution features has been demonstrated by a comprehensive exploration program, and provision should be made for verification of the foundation conditions by inspection of any bedrock exposures made during construction. Any solution features that do exist should be located and defined for the purpose of remedial measures.

Investigations may be carried out with borings or by borings in conjunction with accessible excavations, soundings, geophysical surveys*, or a suitable combination of such methods. The details of a suitable program of investigation will depend on the details of the site geology and on the nature and design of the structures involved. However, it should be formulated and carried out in such a way as to assure the detection of any cavity, whether air-, water-, or soil-filled, that is of such size and at such location that it could endanger the integrity of Category I structures.

Any indications of the presence of cavities, such as zones of lost circulation, mud fillings, poor core recovery, or dropping or settling of drilling rods, or anomalies that suggest voids in geophysical surveys or in situ tests, should be defined geometrically by means of accessible excavations or inclined borings. While such indications may represent joints, they are also consistent with large solution voids that may be open or fully or partially filled with water or soil.

The occurrence, distribution, and geometry of subsurface cavities are highly unpredictable, and it can not be assured that any preconstruction exploration program, no matter how competently planned and executed, will

* Various geophysical techniques for the detection of cavities are discussed in Reference 4.

fully reveal all subsurface voids. Therefore, where a site is on solution-susceptible rock, provision should be made for inspection of the rock after stripping or excavation is complete, if the rock is exposed, and for necessary remedial grouting or other corrective measures.

Faults or fracture zones. The presence of faulting or fracture zones may be indicated by surface features, linears or lineaments on aerial photographs or remote sensing imagery, by plausible projections of faults from locations off-site, or by evidence from subsurface or geophysical exploration. A careful study should be made of the site and its environs to determine whether such evidence of faulting exists, and any faulting indicated by documented earlier geological studies should be investigated to determine whether its existence is supported by such evidence.

The scope of the required investigations for the purposes of determining the vibratory ground motion associated with the SSE and for determining the extent to which the plant need be designed for surface faulting is described in Section IV of Appendix A, 10 CFR Part 100.

Sites that include capable faults (as defined in Appendix A, 10 CFR Part 100) are considered to be unsuitable for nuclear power plants*. Other faults or significant fractures that occur in locations where they might affect the safety of Category I structures should be investigated in sufficient detail to define their geometry, including length, inclination, and displacement; the nature and condition of materials in the zone of faulting or fracturing; and the location and condition of any subsidiary faults or fractures associated with them. These investigations should be

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* Regulatory Guide 4.7.

carried out by means of a suitable coordinated program of trenches, borings, and appropriate geophysical surveys.

Trenches should be used at the locations of all Category I structures that lie on the surface traces of fault or fracture zones. The surfaces exposed in trenches should be carefully mapped, logged, and photographed by qualified engineering geologists, and samples should be obtained to represent all soil or rock units exposed and all materials, such as fault gouge or fillings, found in the fault or fracture zone. Subsurface investigations should include a combination of vertical borings and inclined borings, with appropriate sampling and logging of the boreholes.

5. Methods of Subsurface Investigation

General. Methods or techniques of subsurface investigation discussed in this section include methods of access for sampling, testing, or observation; methods of recovering samples of geologic materials; and methods of in situ testing to determine the mechanical properties or identity of soils or rocks.

A number of important and widely used techniques for subsurface investigation are listed in tabular form in Appendix C, which also contains citations of appropriate standards or descriptions of procedures from sources in the literature, and general guidelines on the applicability of these methods and on some limitations and potential pitfalls in their use. The applicability as indicated in Appendix C is not definitive. The use of listed techniques other than as indicated is acceptable when it can be shown that they yield satisfactory results. Also, techniques other than those listed may be used wherever they are appropriate to the site conditions and to the results required.

The attainment of satisfactory and reliable results in drilling, sampling, and testing is dependent on proper procedures being followed in all details of operations and on timely recognition and correction of potential sources of error. It is essential that field operations be supervised by qualified professional personnel at the site of operations and that systematic standards of practice be followed. Written instructions should be provided for the guidance of field personnel in procedures to be followed for drilling and sampling operations and for in situ testing. Such instructions should describe the procedures to be followed in all aspects of the field operations. Where appropriate, this may be done by reference to published standards, manuals, or the like, copies of which should be provided for use in the field. Any planned deviations from materials that are incorporated by reference in the instructions should be explicitly stated. Also, field records should show wherever conditions encountered in the field required deviation from the written instructions.

<u>Drilling</u>. In nearly every site investigation, primary reliance is placed on borings and borehole sampling. Drilling methods and procedures used should be consistent with sampling requirements and with the methods of sample recovery that are to be employed. Comprehensive descriptions of all phases of drilling and sampling operations are given by Hvorslev (11). The U. S. Army Manual, EM 1110-2-1907 (29), and the U. S. Navy Design Manual, NAVFAC DM-7 (31) are useful guides for field engineers; they may, however, require supplementation to meet the needs of particular projects.

Borings used for undisturbed sampling of soils should be at least three inches in diameter, and the top of the hole should be protected by suitable surface casing where needed. Below the surface, the borehole

should be protected by drilling fluid or casing, as necessary, to prevent excessive caving and disturbance of materials to be sampled. The use of bottom-discharge bits, or of washing with open-ended pipe, for cleaning or advancing the borehole should not be permitted. Washing may be used for cleaning the borehole if it is done with low to medium fluid pressure and with upward-deflected jets.

Systematic records should be kept of all operations and of ground conditions noted during drilling. The groundwater or drilling mud level should be measured at the start and end of work each day, for borings in progress, at the completion of drilling, and 24 hours or more after drilling is completed. All depths and amounts of water or drilling mud losses, together with depths at which circulation is recovered, should be recorded and reported on boring logs and on geological or soils cross sections. This should also be done for settling or dropping of drill rods, abnormally low resistance to drilling or advance of samplers, core losses, instability or heave of the bottom of boreholes, influx of groundwater, and any other abnormal feature or occurrence.

Depths should be measured to the nearest one-tenth foot, and they should be referrable to the elevation datum used for the site so that the elevations of points in the borehole can be determined with an accuracy of one-half foot, or better. Deviation surveys should be run in all boreholes that are used for crosshole seismic tests. Before abandonment, each borehole should be backfilled or grouted with material that will prevent movement of groundwater in the borehole.

Sampling. Samples should contain all of the mineral constituents of the strata from which they are taken, and in the same proportions, and

should be uncontaminated (representative samples). For some purposes, it is required also that they represent the in situ structure sufficiently well that they are suitable for tests of properties that depend on the structure (undisturbed samples).

Undisturbed samples of soils may be obtained by hand trimming of materials exposed in accessible excavations (see Appendix C), or by means of any of several types of borehole samplers such as thin-wall tube samplers. Where tube samplers are used, the following criteria should be met:

i. Tubes used should meet the specifications of ASTM Standard D 1587- 67 (1);

ii. The Area Ratio* of the sampler should not exceed 13 percent, and preferably should not exceed 10 percent;

iii. The Specific Recovery Ratio* should be between 95 percent and 100 percent;

iv. The Inside Clearance Ratio* should be the minimum value required for complete sample recovery;

v. The samples recovered should contain no visible distortion of strata, or opening or softening of materials.

The recovery of undisturbed samples of good quality is dependent on rigorous attention to details of equipment and procedure. Proper cleaning of the hole, by methods that do not produce avoidable disturbance of the soil, is required before sampling; the sampler should be advanced in a manner that does not produce avoidable disturbance; in the use of fixed-piston samplers, the drilling rig should be firmly anchored, or the piston should be fixed to an external anchor, to prevent its moving upward during

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* Defined in Appendix B.

the push of the sampling tube; and care should be taken to assure that the sample is not disturbed during removal from the borehole or disassembly of the sampler. References 29 and 31 provide descriptions of suitable procedures for obtaining undisturbed samples.

With the conscientious use of proper field techniques, undisturbed samples can normally be recovered by means of thin-wall tube samplers without serious difficulty in normally consolidated clays and silts. Recovery of good undisturbed samples in sands requires greater care than in clays, but with due care and attention to detail, adequate undisturbed samples can be obtained with thin-wall tube piston samplers in most sands that are free of boulders and gravel particles. Appendix C lists a number of sampling methods that are suitable for use in these and other materials.

Undisturbed samples of boulders, gravels, or sand-gravel mixtures generally can not be obtained from boreholes by means of presently available samplers. Test pits, shafts, or other accessible excavations may be used with hand sampling methods where in situ density must be determined. Where the materials in question are below the groundwater table, dewatering by means of well points or other suitable methods is required. Osterberg and Varaksin (19) describe a sampling program using dewatering of a shaft in sand with a frozen surrounding annulus. Samples suitable for density determinations, though not for tests of mechanical properties, may sometimes be obtained from boreholes with the help of chemical stabilization or impregnation (12, 32). Special precautions are required when toxic chemicals are used. Also, where aquifers are involved, it may not be permissible to inject chemicals or grouts into them. Useful discussions of methods of sampling granular soils are given by Hvorslev (11) and Barton (3).

Handling, field storage, and transportation of samples. Treatment of samples after their recovery from the ground is as critical to their quality as the procedures used in obtaining them. Samples of cohesionless soils are particularly sensitive to disturbance in handling, and require extreme care during removal from the borehole, removal of the sample tube from the sampler, and subsequent handling, in order to prevent disturbance from impact and vibration. Reference 29 gives details of procedures that are appropriate for labeling, field preparation, field storage, and transportation of undisturbed samples of both cohesive and cohesionless soils. Special precautions are required in transportation of undisturbed samples, because of the greatly increased exposure to vibration and impact. They should be kept in an upright (vertical) position at all times, should be well padded to isolate them from vibration and impacts, and should be transported with extreme care at moderate speed. Transportation by commercial carriers should not be permitted. If the configuration or nature of the undisturbed samples is such that these procedures are inapplicable, the samples should be handled by methods that give them equivalent protection from disturbance.

Disturbed or representative samples of small size may be sealed in the same way as undisturbed samples, if in tubes, or may be placed in suitably marked, noncorroding, airtight containers. Large representative samples may be placed in noncorroding cans or other vessels, or in bags of plastic or tightly woven cloth that does not permit loss of fine particles by sifting. Such samples may be transported by any convenient means.

Rock cores should be stored and transported in strong boxes, provided with suitable dividers to prevent shifting of the cores in either direction.

They should be clearly and unambiguously labeled to identify the site and boring number, the core interval, and the top and bottom of the core. If it has a removable lid, labeling should be placed on and inside the body of the box, in addition to any that may be placed on the lid. Samples to be used for fluid content determinations, and shale samples to be used for tests of mechanical properties, should be protected from changes in fluid content. Core samples should be transported with due care to avoid breakage or disturbance.

6. Spacing and Depth of Subsurface Investigations

General considerations. Depth and spacing requirements for subsurface investigations are determined by the types of structures involved and by the character of the foundation materials. It is not usually possible to establish *a priori* a minimum level of exploratory effort that will be adequate to define the geological conditions and to provide other required data at a particular site, because it is dependent on the site conditions. Therefore, these guidelines may not be adequate to deal with every case that may be encountered in the field. In any case, the need to assure the safety of the plant should take precedence over any arbitrary rules.

Subsurface conditions may be grouped into three broad classes on the basis of the kinds of considerations that govern the necessary spacing and arrangement of subsurface explorations.

i. Conditions may be considered to be "normal" if the features to be defined are large compared to practicable boring spacing, and all significant stratigraphic boundaries are correlatable from one boring or sounding location to the next with relatively smooth variations in thicknesses or properties of the units. Occasional anomalies or a limited number of

abrupt lateral variations may occur; if so, they should be considered in determining the spacing and layout of subsurface explorations. This condition permits the maximum spacing of borings for adequate definition of the subsurface conditions on the site, and it is the condition considered for the rules on spacing and depth as given in Appendix D.

ii. Occasionally deposits may be encountered in which the depositional patterns are so complex that only the major stratigraphic boundaries are correlatable and material types or properties may vary within major units in an apparently random manner from one boring to another. The number of borings required will be determined by the need for establishing average values of the material properties, cumulative thicknesses of the various material types, and the degree of variability and ranges of these quantities. It should therefore be established by tests for the statistical significance of the data, with a lower limit as in the normal condition.

iii. A difficult exploration problem may be presented when geological associations or other evidence suggests the presence of local anomalies or discontinuities, such as cavities, sinkholes, fissures, faults, or pockets of unstable or highly compressible soil. In such a case, the normal exploratory work should be supplemented by borings or soundings at a spacing small enough to assure the detection of any such feature that is of sufficient size to affect the structures, and penetrating to a depth below the greatest depth at which their presence could adversely affect the safety of the structures. A properly planned program of geophysical investigations may be used to supplement the boring and sounding program, in which case the spacing of borings and soundings should be such as to assure the detection, either by direct penetration or by geophysical measurements, of any such feature that is of sufficient size to affect the structures.

Layout of subsurface explorations. The locations of the subsurface investigations should be well-disposed over the site, so as to best define the geological conditions. Usually a uniform grid does not provide the most effective disposition of exploration locations, unless the site conditions are very uniform or are randomly variable. The initial borings should be laid out on the basis of conditions indicated by preliminary reconnaissance, and locations for subsequent explorations should be chosen so as to best define the conditions revealed during the course of the work.

The locations of subsurface explorations should be aligned wherever feasible to accommodate the construction of geological cross sections in various directions through critical parts of the site.

In the investigation of known or suspected faults, borings should be laid out in line parallel to the alignment of the fault. Inclined borings should be used in addition to vertical borings to assure that the fault plane will be intersected.

Spacing and depth by zone. Exploratory zones within which subsurface exploration for a particular project may be carried out are designated as Zones I through III, as defined in Section B. Requirements of spacing and depth are as follows:

i. Zone I. Appendix D gives standards of spacing and depth of exploration generally acceptable for Zone I under normal conditions. Greater spacings or lesser depths may be acceptable in cases where they can be shown to be adequate.

ii. Zone II. Subsurface explorations should be carried out with spacing and depth of penetration as necessary to define the general geological conditions of the site. In planning the exploration program for

Zone II, consideration should be given to the possibility that the planned locations of structures may be changed, and to the possibility that such changes may require an expensive second round of exploration in order to define adequately the subsurface conditions at the final locations.

iii. Zone III. Subsurface investigations need not be done routinely in Zone III, but may be needed in some instances to define geological conditions necessary to an evaluation of the site geology. Detailed exploration of faults in Zone III will be required in some instances, in accordance with the requirements of Appendix A, 10 CFR Part 100.

7. Investigations Required During Construction

It is essential to verify during construction that in situ conditions are the same as those used for analysis and design. Excavations made during construction provide opportunities for obtaining additional geological and geotechnical data at relatively little cost. All construction excavations on the site should be geologically mapped and logged in detail, with particular attention to the identification of any thin strata or other geological features that might be important to the foundation behavior but might be difficult to detect in boreholes. If subsurface conditions differ from those anticipated in such a way as to cast doubt on the foundation performance, additional borings or soundings should be made to resolve such doubt.

In deep excavations, the foundations may be endangered by movements of soil adjacent to the excavation. Also, in some types of soils, if excessive displacements are permitted to occur, the strength might be reduced to such an extent that the soil is rendered permanently unfit for use under or adjacent to important structures. The sides of deep excavations in soil and the surface of the ground adjacent should be monitored throughout the

time the excavations are open to observe any settlement or horizontal movements. The bottoms of excavations should be monitored to observe any heave.

All piezometers on the site should be regularly monitored. If materials beneath the subgrade elevation are stratified and contain sand or silt layers, or if artesian pressures exist, piezometers should be installed at the locations of excavations, extending to at least the depth of subgrade elevation below the original ground surface, to monitor groundwater pressures and the stability of the excavation against uplift. Where dewatering is involved, piezometers should be installed to monitor water levels beneath the excavation and in the ground adjacent to it.

APPENDIX A

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APPENDIX B

DEFINITIONS

For the purposes of this guide, the following words and terms are used with intended meanings as indicated:

Accessible excavation means an excavation, made for the purpose of investigating materials or conditions below the ground surface, of such shape and dimensions as to permit the entry of personnel for direct examination, testing, or sampling.

Area ratio, of a sampling device, is defined as:

$$C_a = \frac{D_w^2 - D_e^2}{D_e^2}$$

where D_w is the outside diameter of that part of the sampling device that is forced into the soil, and D_e is the diameter of the cutting edge.

Boring means an exploratory hole in soil or rock, or both, made with removal of materials in the form of samples or cuttings (cf. sounding).

Disturbed sample means a sample whose internal structure has been damaged to such a degree that it does not reasonably approximate that of the material in situ. Such a sample may be completely remolded, or it may bear a resemblance to an undisturbed sample in having preserved the gross shape given it by a sampling device.

In situ test means a test performed on in situ soil or rock for the purpose of determining some physical property. As used in this guide, it includes a geophysical measurement from which a value of a physical property can be inferred or determined by correlations.

Inside clearance ratio, of a sampling device, is defined as:

$$C_i = \frac{D_s - D_e}{D_e}$$

where D_s is the inside diameter of the sample tube or liner and D_e is the diameter of the cutting edge.

Piezometer means a device or instrument for measuring pressure head in groundwater or the position of the groundwater table.

Principal borings means those borings that are used as the principal source of subsurface information to define the geology of the site and to determine the properties of the subsurface materials, and which are used to explore and sample all soil or rock strata within the interval penetrated. Not included are borings from which samples are not taken, borings used to investigate specific or limited intervals, or borings so close to others that the information yielded represents essentially a single location.

Remolded sample means a sample which has been disturbed to such an extent that its structure is determined by the stresses and strains undergone during and after sampling, and the effect of in situ conditions is obscured.

Representative sample means a sample that contains all of the mineral constituents of the stratum from which it is taken, in the same proportions, with the same grain-size distribution, and is uncontaminated by foreign materials or by chemical alteration.

Sounding means an exploratory penetration below the ground surface by means of a device that is used to measure or observe some property of the materials penetrated, usually without recovery of samples or cuttings.

Specific recovery ratio, in the advance of a sample tube, is defined as:

$$R_s = \frac{\Delta L}{\Delta H}$$

where ΔL is the increment of length of sample in the tube corresponding to an increment ΔH of sampler advance.

Structure, in soil or rock, means a complex physical-mechanical property, components of which are the sizes, shapes, and arrangements of the constituent grains and intergranular matter, and the forces acting among the constituents.

Supplementary borings or supplementary soundings means borings or soundings that are made in addition to principal borings, for some specific or limited purpose.

Undisturbed sample means a sample obtained and treated in such a way that disturbance of its original structure is insignificant, so that the sample is suitable for laboratory tests of material properties that depend on structure.

Zone I means a composite area, defined for the purposes of site investigation, consisting of the immediate areas of the foundations of safety-related (Seismic Category I) structures or systems, and all other areas in which foundation failures or ground instability could endanger such structures or systems.

Zone II means a composite area, defined for the purposes of site investigation, consisting of those areas within the site boundary, or in which structures or systems appurtenant to the plant are located, but which are not included in Zone I.

Zone III means a composite area, defined for the purposes of site investigation, consisting of those areas that are not included in Zones I or II, that are in the environs of the site and have close geological affinities to the site, and in which an understanding of the geological conditions is needed for a complete assessment of the geology of the site.

APPENDIX C

METHODS OF SUBSURFACE EXPLORATION

METHOD	PROCEDURE	APPLICABILITY	LIMITATIONS AND PITFALLS
Methods of Access for Sampling, Test, or Observation			
Pits, Trenches Shafts, Tunnels	Excavation made by hand, large auger, or digging machinery. (11, pp. 66-71)	Visual observation, photography, disturbed and undisturbed sampling, in situ testing of soil and rock.	Depth of unprotected excavations is limited by groundwater or safety considerations.
Auger Boring	Boring advanced by hand auger or power auger. (11, pp. 61-64)	Recovery of remolded samples, location of groundwater table. Access for undisturbed sampling of cohesive soils.	Will not penetrate boulders or most rock.
Hollow Auger Boring	Boring advanced by means of continuous-flight helix auger with hollow center stem. (6)	Access for undisturbed or representative sampling through hollow stem with thin-wall tube sampler, core barrel, or split-barrel sampler.	Should not be used with plug in granular soils. Not suitable for undisturbed sampling in loose sand or silt. (20, pp. 105-106)
Wash Boring	Boring advanced by chopping with light bit and by jetting with upward-deflected jet. (11, pp. 52-54)	Cleaning out and advancing hole in soil between sample intervals.	Suitable for use with sampling operations in soil only if done with low water velocities and with upward-deflected jet.

Rotary Drilling	Boring advanced by rotating drilling bit with cuttings removed by circulating drilling fluid. (11, pp. 57-61)	Cleaning out and advancing hole in soil or rock between sample intervals.	Drilling mud should be used in granular soils. Bottom-discharge bits are not suitable for use with undisturbed sampling in soils, unless combined with protruding core barrel, as in Denison sampler.
Percussion Drilling	Boring advanced by air-operated impact hammer.	Detection of voids and zones of weakness in rock by changes in drill rate or resistance. Access for in situ testing or logging.	Not suitable for use in soils.
Cable Drilling	Boring advanced by repeated dropping of heavy bit and removal of cuttings by bailing. (11, pp. 54-57)	Advancing hole in soil or rock. Access for sampling, in situ testing, or logging in rock. Penetration of hard layers, gravel, or boulders in auger borings.	Causes severe disturbance in soils; not suitable for use with undisturbed sampling methods.
Continuous Sampling or Displacement Boring	Boring advanced by repeated pushing of sampler, or closed sampler is pushed to desired depth and sample is taken (11, pp. 51-52)	Recovery of representative samples of cohesive soils, undisturbed samples in some cohesive soils.	Effects of advance and withdrawal of sampler result in disturbed sections at top and bottom of sample. In some soils, entire sample may be disturbed. Not suitable for use in cohesionless soils.

Methods of Sampling Soil and Rock

Hand-Cut Block or Cylindrical Sample	Sample is cut by hand from soil exposed in excavation. (30, pp. 346-349; 27, pp. 312-314)	Highest-quality undisturbed samples in cohesive soils, cohesionless soils, and soft rock.	Requires accessible excavation and dewatering if below water table. Extreme care is required in sampling cohesionless soils.
Thin-walled Tube Samplers	Thin-walled tube is pushed into soil at bottom of boring. (ASTM D1587-67; 29, Ch. 4)	Undisturbed or representative samples in cohesive soils and cohesionless soils finer than gravel.	Not suitable for use in extremely hard soils, gravel, or stony soils. Strict attention to details of equipment and procedure is required to obtain undisturbed samples of good quality. (29, Ch. 3 & 4; 11, pp. 83-139)
(Major types of Thin-walled Tube Samplers are listed below)			
a. Fixed-Piston Sampler	Thin-walled tube is pushed into soil, with fixed piston in contact with top of sample during push. (29, Ch. 3; 11, pp. 128-130; 30, pp. 349-379)	Undisturbed samples in cohesive soils, silts, and sands, above or below the water table.	Some types do not have positive prevention of piston movement.
b. Hydraulic Piston Sampler (Osterberg)	Thin-walled tube is pushed into soil by hydraulic pressure. Fixed piston in contact with top of sample during push. (17; 18; 29, Ch. 3)	Undisturbed samples in cohesive soils, silts, and sands, above or below the water table.	Not possible to determine amount of partial sampler penetration during push. Does not have vacuum-breaker in piston.

c. Free-Piston Sampler	Thin-walled tube is pushed into soil. Piston rests on top of soil sample during push. (29, Ch. 3; 11, p. 131)	Undisturbed samples in stiff cohesive soils, representative samples in soft to medium cohesive soils and silts.	Not suitable for sampling in cohesionless soils. Free piston provides no control of specific recovery ratio.
d. Open Drive Sampler	Thin-walled, open tube is pushed into soil. (11, p. 133; 30, pp. 361-367)	Undisturbed samples in stiff cohesive soils. Representative samples in soft to medium cohesive soils and silts.	Not suitable for sampling in cohesionless soils or for undisturbed sampling in uncased boreholes. No control of specific recovery ratio.
Swedish Foil Sampler	Sample tube is pushed into soil while stainless steel strips unrolling from spools envelop sample. Piston, fixed by chain from surface, maintains contact with top of sample. (27, pp. 308-310; 13)	Continuous undisturbed samples up to 20 metres long in very soft to soft clays.	Not suitable for use in soils containing gravel, sand layers, or shells, which may rupture foils and damage samples. Difficulty may be encountered, in alternating hard and soft layers, with squeezing of soft layers and reduction in thickness. Requires experienced operator.
Pitcher Sampler	Thin-walled tube is pushed into soil by spring above sampler while outer core bit reams hole. Cuttings removed by circulating drilling fluid. (27, pp. 310-312)	Undisturbed samples in hard, brittle, cohesive soils and sands with cementation. Representative samples in soft to medium cohesive soils and silts. Disturbed samples may be obtained in cohesionless materials with variable success.	Frequently ineffective in cohesionless soils.

Denison Sampler	Hole is advanced and reamed by core drill while sample is retained in nonrotating inner core barrel with corecatcher. Cuttings removed by circulating drilling fluid. (27, pp. 312-313; 30, pp. 355-361)	Undisturbed samples in stiff to hard cohesive soil, sands with cementation, and soft rocks. Disturbed samples may be obtained in cohesionless materials with variable success.	Not suitable for undisturbed sampling in loose cohesionless soils or soft cohesive soils.
Split-Barrel or Splitspoon Sampler	Split-barrel tube is driven into soil by blows of falling ram. Sampling is carried out in conjunction with Standard Penetration Test. (ASTM D 1586-67)	Representative samples in soils other than coarse granular soils.	Samples are disturbed, and not suitable for tests of mechanical properties.
Auger Sampling	Auger drill, used to advance hole, is withdrawn at intervals for recovery of soil samples from auger flights. (ASTM D 1452-65)	Remolded samples in most soils.	Samples not suitable for tests of mechanical properties or density. Large errors in locating strata boundaries may occur without close attention to details of procedure. (27, pp. 299-300) In some soils, particle breakdown by auger or sorting effects may result in errors in determining gradation.
Rotary Core Barrel	Hole is advanced by core bit, while core sample is retained within core barrel or within stationary inner tube. Cuttings removed by circulating drilling fluid. (ASTM D 2113-70)	Core samples in competent rock and hard soils with single-tube core barrel. Core samples in poor or broken rock may be obtainable with double-tube core barrel with bottom-discharge bit.	Because recovery is poorest in zones of weakness, samples generally fail to yield positive information on soft seams, joints, or other defects in rock.

Shot Core Boring (Calyx)	Boring advanced by rotating single core barrel which cuts by grinding with chilled steel shot fed with circulating wash water. Used shot and coarser cuttings are deposited in an annular cup, or calyx, above the core barrel. (11, pp. 156-157)	Large diameter cores and accessible boreholes in rock.	Can not be used in drilling at large angles to the vertical. Often ineffective in securing small diameter cores.
Oriented Integral Sampling	Reinforcing rod is grouted into small-diameter hole, then overcored to obtain an annular core sample. (21)	Core samples in rock, with preservation of joints and other zones of weakness.	Samples are not well-suited to tests of mechanical properties.
Wash Sampling or Cuttings Sampling	Cuttings are recovered from wash water or drilling fluid.	--------------------	Sample quality is not adequate for nuclear power plant site investigations.
Submersible Vibratory (Vibracore) Sampler	Core tube is driven into soil by vibrator. (28)	Continuous representative samples in unconsolidated marine sediments.	Because of high area ratio and effects of vibration, samples may be disturbed.
Underwater Piston Corer	Core tube attached to drop weight is driven into soil by gravity after a controlled height of free fall. Cable-supported piston remains in contact with soil surface during drive (16)	Representative samples in unconsolidated marine sediments.	Samples may be seriously disturbed. (15)

Gravity Corer	Open core tube attached to drop weight is driven into soil by gravity after free fall. (16)	Representative samples at shallow depth in unconsolidated marine sediments.	No control of specific recovery ratio. Samples are disturbed.

Methods of In Situ Testing of Soil and Rock

Standard Penetration Test	Split-barrel sampler is driven into soil by blows of falling weight. Blow count for each 6 inches of penetration is recorded. (ASTM D 1586-67)	Blow count is used as an index of consistency or density of soil. May be used for detection of changes in consistency or relative density in clay or sands. May be used with empirical correlations to estimate relative density of clean sand.	Extremely unreliable in silts, silty sands, or soils containing gravel. In sands below water table, positive head must be maintained in borehole. Determination of relative density in sands requires site-specific correlation or highly conservative use of published correlations. Results are sensitive to details of apparatus and procedure.
Dutch Cone Penetrometer	Steel cone is pushed into soil and followed by subsequent advance of friction sleeve. Resistance is measured during both phases of advance. (23)	Detection of changes in consistency or relative density in clays or sands. Used to estimate static undrained shear strength of clay. Used with empirical correlations to obtain estimate of static compressibility of sand.	Strength estimates require on-site verification by other methods of test.
Field Vane Shear Test	Four-bladed vane is pushed into undisturbed soil, then rotated to cause shear failure on cylindrical surface. Torsional resistance versus angular deflection is recorded. (ASTM D 2573-72)	In situ measurement of static undrained shear strength and sensitivity of clays.	Not suitable for use in silt, sand, or soils containing appreciable amounts of gravel or shells. May yield unconservative values of shear strength in fissured clay soils, or where strength is strain-rate dependent.

Drive-Point Penetrometer	Expendable steel cone is driven into soil by blows of falling weight. Blow count versus penetration is recorded. (27, pp. 322-324)	Detection of gross changes in consistency or relative density. May be used in some coarse granular soils.	Provides no quantitative information on soil properties.
Plate Bearing Test (Soil)	Steel loading plate is placed on horizontal surface and is statically loaded, usually by hydraulic jack. Settlement versus time is recorded for each load increment. (ASTM D 1194-72)	Estimation of bearing capacity and short-term settlement of footings on soil. May be used at ground surface, in excavations, or in boreholes.	Results can be extrapolated to loaded areas larger than bearing plate only if properties of soil are uniform with depth. Does not provide information on long-term settlement.
Plate Bearing Test or Plate Jacking Test (Rock)	Bearing pad on rock surface is statically loaded by hydraulic jack. Deflection versus load is recorded. (25, pp. 126-138)	Estimation of elastic moduli of rock masses. May be used at ground surface, in excavations, in tunnels, or in boreholes.	Results can be extrapolated to loaded areas larger than bearing pad only if rock properties are uniform over volume of interest and if diameter of bearing pad is larger than average spacing of joints or other discontinuities.
Pressure Meter Test	Uniform radial pressure is applied hydraulically over a length of borehole several times its diameter. Change in diameter versus pressure is recorded. (25, pp. 141-144; 5)	Estimation of elastic moduli of rocks, and estimation of shear strengths of soils by empirical correlations.	Test results represent properties only of materials in near vicinity of borehole. Results may be misleading in anisotropic materials.

Crosshole Seismic Test	Seismic signal is transmitted from source in one borehole to receiver(s) in other borehole(s), and transit time is recorded. (2)	Measurement of compression wave velocity and shear wave velocity in soils and rocks.	Requires deviation survey of boreholes to eliminate errors due to deviation of holes from vertical. Refraction of signal through adjacent high-velocity beds must be considered in interpretation.
Uphole/Downhole Seismic Test	Seismic signal is transmitted between borehole and ground surface, and transit time is recorded. (2)	Measurement of compression wave velocity and shear wave velocity in soils and rocks.	Apparent velocity obtained is time-average for all strata between source and receiver.
Acoustic Velocity Log	Logging tool contains transmitting transducer and two receiving transducers separated by fixed gage length. Signal is transmitted through rock adjacent to borehole and transit time over the gage length is recorded as difference in arrival times at the receivers. (10, Ch. 21; 22, Ch. 7)	Measurement of compression wave velocity. Used primarily in rocks to obtain estimate of porosity.	Results represent only the material immediately adjacent to the borehole. Can be obtained only in uncased, fluid-filled borehole. Use is limited to materials with P-wave velocity greater than that of borehole fluid.
3-D Velocity Log	Logging tool contains transmitting transducer and receiving transducer separated by fixed gage length. Signal is transmitted through rock adjacent to borehole and wave train at receiver is recorded. (7)	Measurement of compression wave and shear wave velocities in rock. Detection of void spaces, open fractures, and zones of weakness.	Results represent only the material immediately adjacent to the borehole. Can be obtained only in uncased, fluid-filled borehole. Correction required for variation in hole size. Use is limited to materials with P-wave velocity greater than that of borehole fluid.

Electrical Resistivity Log	Apparent electrical resistivity of soil or rock in neighborhood of borehole is measured by in-hole logging tool containing one of a wide variety of electrode configurations. (10, Ch. 14; 22, Chs. 3-6)	Appropriate combinations of resistivity logs can be used to estimate porosity and degree of saturation in rocks. In soils, may be used as qualitative indication of changes in void ratio or water content, for correlation of strata between boreholes, and for location of strata boundaries.	Can be obtained only in uncased boreholes. Hole must be fluid-filled or electrodes must be pressed against wall of hole. Apparent resistivity values are strongly affected by changes in hole diameter, strata thickness, resistivity contrast between adjacent strata, and resistivity of drilling fluid.
Neutron Log	Neutrons are emitted into rock or soil around borehole by a neutron source in the logging tool, and a detector isolated from the source responds to either slow neutrons or secondary gamma rays. Response of detector is recorded. (10, Ch. 15; 22, Ch. 9)	Useful for correlation of strata between boreholes and for location of strata boundaries. Provides an approximation to water content, and can be run in cased or uncased, fluid-filled or empty boreholes.	Because of very strong borehole effects, results are generally not of sufficient accuracy for quantitative engineering uses.
Gamma-Gamma Log ("Density Log")	Gamma rays are emitted into rock around the borehole by a source in the logging tool, and a detector isolated from the source responds to back-scattered gamma rays. Response of detector is recorded. (22, Ch. 8)	Estimation of bulk density in rocks, qualitative indication of changes in density of soils. May be run in empty or fluid-filled holes.	Effects of borehole size and density of drilling fluid must be accounted for. In present state of development, not suitable for quantitative estimate of density in soils other than those of "rock-like" character. Can not be used in cased boreholes.

Borehole Cameras	Film-type or television camera in a suitable protective container is used for observation of walls of borehole. (14)	Detection and mapping of joints, seams, cavities, or other visually observable features in rock. Can be used in empty, uncased holes or in holes filled with clear water.	Results are affected by any condition that affects visibility.

APPENDIX D

SPACING AND DEPTH OF SUBSURFACE EXPLORATIONS FOR ZONE I[1]

TYPE OF STRUCTURE	SPACING OF BORINGS[2] OR SOUNDINGS	MINIMUM DEPTH OF PENETRATION
General	For normal conditions, where average continuity of subsurface strata is found, spacing according to the type of structure involved, with at least one boring at the site of any Seismic Category I structure. Where highly variable conditions are found, required spacing is as needed to obtain a statistical measure of subsoil properties and their variability, with a lower limit as in the normal condition. Where cavities or other discontinuities of engineering significance may occur, the normal exploratory work should be supplemented by borings or soundings at a spacing small enough to detect any such feature of significant size.	Depth, as given below, according to the type of structure, except that all borings should be extended to sufficient depth to sample all materials that may swell during excavation, or consolidate subsequent to construction, or liquefy under earthquake loading, or whose strength would affect stability. Where soils or unindurated sediments are very thick, the maximum required depth, denoted d_{max}, may be taken as 450 ft, or the depth at which the shear wave velocity exceeds 3,000 ft/sec, whichever is less. If competent rock is encountered at lesser depths than those given, borings should penetrate to greatest depth where discontinuities or zones of weakness can affect foundations, but should penetrate at least 20 ft into sound rock. For shale or soft rock, depths should be as for soils.

Foundation Structures, including buildings, retaining walls, concrete dams, storage tanks	Principal borings: one per 2,500 sq ft, or one per 50 lineal feet for essentially linear structures, where conditions are found to be relatively uniform. Supplementary borings or soundings as necessary to define any anomalies.	Principal borings: at least one-fourth, but not less than one, of the principal borings to penetrate into sound rock or to a depth equal to d_{max}. Others to a depth below subgrade elevation equal to the width of the structure, to a depth equal to the subgrade depth below the original ground surface, or to a depth at which the change in stress at completion of work is no more than 10 percent of the in situ effective stress; whichever is greater. Supplementary borings as required to define any anomalies.
Earth dams, dikes, levees, and embankments.	Principal borings: one per 50 lineal feet of the structure. Supplementary borings or soundings as required to define any anomalies.	Principal borings: one per 200 lineal feet to penetrate into sound rock or to d_{max}. Others should penetrate all strata whose strength would affect stability. For water-impounding structures, to sufficient depth to define all aquifers and zones of underseepage that could affect performance of structure. Supplementary borings or soundings as required to define any anomalies.
Deep cuts,[3] canals below grade	Principal borings: one per 50 lineal feet. Supplementary borings or soundings as required to define any anomalies.	Principal borings: one per 200 lineal feet to penetrate into sound or to d_{max}. Others to a depth below the bottom elevation equal to the depth of cut. Supplementary borings or soundings as required to define any anomalies.

Pipelines	Principal borings: one per 50 lineal feet for buried pipelines; at least one boring for each footing for pipelines above ground. Supplementary borings or soundings as required to define any anomalies.	Principal borings: For buried pipelines, one per 100 lineal feet to penetrate into sound rock or to d_{max}. Others to 10 ft below the invert elevation. For pipelines above ground, depths as for foundation structure. Supplementary borings or soundings as required to define any anomalies.
Reservoirs, impoundments	Principal borings: one per 20,000 sq ft of interior area of the impoundment, in addition to borings at the locations of dams or dikes. Supplementary borings or soundings as necessary to define any anomalies.	Principal borings: at least one-fourth, but not less than one, of the principal borings to penetrate into sound rock or to d_{max}. Others to a depth of 25 ft below subgrade elevation. Supplementary borings or soundings as required to define any anomalies.

Notes: 1. As determined by the final locations of Category I structures.
2. Includes shafts or other accessible excavations that meet depth requirements.
3. Includes temporary cuts, open during construction, where loss of strength due to excessive deformations would affect ultimate site safety.

APPENDIX E

REVIEW OF SUGGESTED STANDARDS FOR NUMBER AND DEPTH OF BORINGS FOR SITE INVESTIGATIONS

The table in this appendix summarizes the results of a review of published recommendations for depths and number of borings that should be provided for investigations of the sites of major engineering projects. This compilation is not exhaustive, but is representative of the published expression of authoritative professional opinion on the subject. The work was done to aid in the formulation of the proposed guidelines that are given in Appendix D. Appendix E is not itself intended to be a part of the proposed guidelines for site investigations.

SUGGESTED STANDARDS FOR NUMBER AND DEPTH OF BORINGS FOR SITE INVESTIGATIONS

Reference	Spacing or Number of Borings	Minimum Depth, D	Type of Construction	Other Remarks
M. Juul Hvorslev, Subsurface Exploration and Sampling of Soils for Civil Engineering Purposes, Waterways Experiment Station, Vicksburg, Miss., 1948.	Such that soil profiles obtained permit reasonably accurate estimate of extent and character of intervening soil or rock masses and will disclose important irregularities in subsurface conditions. A spacing of 25 ft will generally provide adequate information even for erratic conditions.	Borings should penetrate all deposits which are unsuitable for foundation purposes and all compressible strata that will be subjected to stress increase sufficient to materially influence settlement of structure. When structure is to be founded on rock, one or more borings should go 10 to 20 ft into sound rock.	General	Borings should not be located in single straight line, but there should be a sufficient number outside the main line to determine dip and strike of strata or irregularities in profiles at right angle to line. Inclined borings may be used for exploration of fault zones and other irregularities.
	Not less than 3 unless subsurface conditions are known to be very uniform.	De Beer rule*, subject to general rules above.	Foundation structures	Initial borings close to corners of area.
		D = 0.75 to 1.5 H (where foundation failure governs) D = 2H (where settlement governs) where H is height of wall	Retaining and quay walls	Depths are preliminary estimates, and subject to general rules.
		D = 0.5 L for triangular fills D = 1.25L for terraces, where L is average horizontal length of slope.	Terraces and fills	
		D = 0.75 to 1.0 B, where B is bottom width	Deep cuts	
		D = L for levees and earth dams; D = 1.5 to 2.0 H for small concrete dams, where 2L is the bottom width and H the net height.	Dams and levees	

* See p. E-4(Sowers and Sowers, 1970)

(Continued)

SUGGESTED STANDARDS (CONTINUED)

Reference	Spacing or Number of Borings	Minimum Depth, D	Type of Construction	Other Remarks
Hvorslev (Continued)	100 ft, or 1 per 10,000 ft^2	D = 3 to 5 ft for light loads D = 6 to 10 ft for heavy loads	Highways, railroads, airfields	
		D = B, where D is depth below invert elevation, B is gross tunnel width.	Tunnels in soil	
Building Officials Conference of America (BOCA), Basic Building Code/1970, Fifth Edition	1 per 2500 ft^2 of built-over area, plus additional borings as required by building official.	To rock or not less than 50 ft.	Buildings other than residential of more than 3 stories, or 40 ft height, with float, mat, or deep foundation.	
D. H. Trollope, "The Importance of Site Investigation," Proc. Site Investigation Symposium, Institution of Engineers, Australia, 1966.	1 per 2500 ft^2 of construction area not including roads, etc. (minimum 5).	50 ft or 1.5 times "Foundation width" whichever is the greater, or 10 ft into sound rock.	Heavy Industrial; Domestic and Commercial >6 stories	Profile description and physical test results to be certified by qualified engineer. Holes to be at least 3 in. diam; below 6 ft, holes to be protected so that suitable undisturbed samples can be taken.
	1 per 5000 ft^2	6 ft or to sound rock	Roads, etc.	
W. J. Hall, N. M. Newmark, & A. J. Hendron, Jr., Classification, Engineering Properties and Field Exploration of Soils, Intact Rock and In Situ Soil Masses, U. S. Nuclear Regulatory Commission, Report No. WASH-1301, 1974.	..."At least one boring underneath every major installation of a nuclear plant."... "In cases where it is expected there can be a variation in engineering properties...or heavy bearing pressures...it is usually necessary to put down a number of borings around the periphery of major structures and at other selected locations."	"...A number of borings should go into the bedrock."	Nuclear power plants	

(Continued)

SUGGESTED STANDARDS (CONTINUED)

Reference	Spacing or Number of Borings	Minimum Depth, D	Type of Construction	Other Remarks
Shannon & Wilson, Inc., and Agbabian-Jacobsen Associates, Soil Behavior Under Earthquake Loading Conditions: State-of-the-Art Evaluation of Soil Characteristics for Seismic Response Analyses, Report for AEC, 1972.	At least two borings are usually necessary at the smaller and less important facilities, while as many six or more may be required for the larger, more important structures.	...Several borings extending to bedrock, or dense "Rock-Like" soils, or to depths of several hundred feet may be necessary...	Nuclear power plants	For purposes of response calculations, the following approximate accuracies are desirable: Approximate Bedrock Depth Zone, ft — Approximate Accuracy ft 0-100 — 5 100-200 — 5 to 10 200-500 — 20 to 50 500-1000 — ~100 >1000 — ±200
Terzaghi and Peck, Soil Mechanics in Engineering Practice, 2d Ed., Wiley, 1968.	Soundings on 50-ft spacing, followed by borings at locations where average conditions prevail and near points of maximum deviation from average.	First borings to greatest depth D_{max} at which a thick layer of soft clay may have a significant influence on settlement. All other borings and soundings to 10 ft below lowest clay stratum within the depth D_{max}.	Group of Buildings	If bedrock is encountered within the depth D_{max}, the topography of the rock surface must be determined at least approximately by sounding or boring...
Sowers and Sowers, Introductory Soil Mechanics and Foundations, 3rd Ed., McMillan, 1970.	Spacing of borings: Highway 1000-2000 ft Earth dam, dikes 100-200 ft Borrow pits 100-400 ft Multistory buildings 50-100 ft One-story manufacturing plants 100-300 ft For uniform, regular soil conditions the above spacings are often doubled; for irregular conditions they are halved.	For very important heavy structures, such as large bridges or tall buildings ...the borings should extend to rock. Rule of E. De Beer of Geotechnical Institute of Belgium: Borings to depth where $\Delta\sigma = 0.1\bar{\sigma}_o$ (Based on settlement considerations).	General	Impossible to determine spacing of borings a priori. Ordinarily, preliminary estimate is made and either increased or decreased according to uniformity of deposits.

(Continued)

SUGGESTED STANDARDS (CONTINUED)

Reference	Spacing or Number of Borings	Minimum Depth, D	Type of Construction	Other Remarks
Task Committee for Foundation Design Manual, "Subsurface Investigation for Design and Construction of Foundations of Buildings: Part I," Jour. SM&F Div., ASCE, Vol 98, No. SM5, 1972.	Sufficient to determine the stratification and interrelation of the soils.	Borings should be carried to such depth that the net increase in soil stress is less than 10% of the average load of the structure or less than 5% of the effective stress in the soil, whichever is the lesser depth. If bedrock is to be investigated, borings should be at least 10 ft into rock if conditions are well known; if not, they should go 25 ft into sound rock, with one or more 40 ft into sound rock.	Buildings	
ASTM Designation D420-69, Standard Recommended Practice for Investigating and Sampling Soils and Rock for Engineering Purposes. ASTM, Annual Book of ASTM Standards, Part 19, 1974.	Dependent on geologic complexity of site area and on importance of soil and rock continuity to the project design.	Roadbeds, airports, or parking areas: 5 ft below subgrade elevations. Structures or embankments: below the level of significant influence of the load according to stress analysis.	General	
Merlin G. Spangler, Soil Engineering, 2d Ed., International Textbook Co., 1966.	Sufficiently close together to give complete information concerning thickness and extent of each soil stratum. For a building, one hole at each corner and one in the center will provide a good start, and additional holes may be dug as necessary to complete the geological profile.	1-1/2 times the greatest horizontal dimension unless bedrock is encountered at lesser depth.	Heavy buildings	

(Continued)

SUGGESTED STANDARDS (CONCLUDED)

Reference	Spacing or Number of Borings	Minimum Depth, D	Type of Construction	Other Remarks
British Standards Institution, <u>Code of Practice for Foundations</u>, CP 2004, 1972.	Disposition and spacing of trial pits or borings such as to reveal any major changes in thickness, depth, or properties of the strata. Number will vary with size and type of structure, nature of site, completeness of local records. Program should be flexible.	Depth which includes all strata likely to be significantly affected by the structural load.	General	
British Standards Institution, <u>Site Investigations</u>, British Standard Code of Practice, CP 2001, 1957.	Sufficient to give a picture of the probable variation in the subsurface strata over the site. "Closely spaced" in the exploration of soils.	Depth which includes all strata likely to be significantly affected by the structural loading. There are three main considerations that may govern: a. Depth to which soil is significantly stressed. b. Depth to which weathering processes affect soil. (Roads and airfields). c. Depth to reach impermeable strata. (Impounding reservoirs and similar structures)	General	In borings through glacial material, the utmost precaution is necessary to ensure that boulders are not mistaken for the beds of rock.

In accordance with letter from DAEN-RDC, DAEN-ASI dated 22 July 1977, Subject: Facsimile Catalog Cards for Laboratory Technical Publications, a facsimile catalog card in *Library of Congress MARC format* is reproduced below.

Franklin, Arley Graves
  Proposed guidelines for site investigations for foundations of nuclear power plants / by Arley G. Franklin. Vicksburg, Miss. : U. S. Waterways Experiment Station ; Springfield, Va. ; available from National Technical Information Service, 1979.
  31, [27] p. ; 27 cm. (Miscellaneous paper - U. S. Army Engineer Waterways Experiment Station ; GL-79-15)
  Prepared for U. S. Nuclear Regulatory Commission, Washington, D. C., under Contract No. AT(49-24)-0104.
  References: p. A-1--A-3.

1. Foundation investigations. 2. Nuclear power plants. 3. Site investigation. 4. Subsurface exploration. I. United States. Nuclear Regulatory Commission. II. Series: United States. Waterways Experiment Station, Vicksburg, Miss. Miscellaneous paper ; GL-79-15.
TA7.W34m no.GL-79-15